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Do New and Renovated Schools and Kindergartens Secure Sufficiently High Indoor Environmental Quality?

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Abstract

The present work is the part of the RENEW SCHOOL project granted by the Intelligent Energy Europe programme supported by European Commission. The aim is to promote sustainable renovation of educational buildings (schools and kindergartens) that use timber facades. The paper describes the measurements in educational buildings that are newly constructed or that have undergone energy renovation and use timber facades. The purpose of the measurements was to examine the quality of indoor environment in these buildings. The quality was assessed by physical measurements of temperature, relative humidity, light intensity and carbon dioxide concentration performed for a period of up to two month between January and April 2015. The measurements were carried out in one representative classroom in each building. The pupils assessed the classroom environment and rated the intensity of their acute health symptoms. Additionally the teachers assessed the environment in these buildings. To create the reference, measurements were also carried out in five conventional educational buildings, where no renovations were performed. The results suggest that the renovated and new buildings perform more or less similar as their conventional counterparts as regards measured parameters of indoor environment. Subjective evaluations made by pupils and teachers did not always match the physical measurements. There were also differences in subjective evaluations made by children and by teachers. In conclusion, there is no indication that the renovation of educational buildings would reduce indoor environmental quality conditions. Likewise, no considerable improvements are to be expected as well.

Keywords – school; kindergarten; renovation; indoor environmental quality; RENEW School (key words)

1. Introduction

Many educational buildings in Europe were built between the 1950s and 1980s. Many of them will be used for yet additional 20-30 years. In order to meet the strict energy requirements in buildings, these buildings need to undergo renovation and modernization in the coming years. The need for renovation is the consequence of the Directive 2010/31/EU published by the European Commission in 2010. This Directive states that “public bodies should take the lead in bringing their buildings up to the high energy performance levels. In order to achieve this result it would be appropriate for public authorities to at least double the current renovation rate”. Additionally this Directive states that “public authorities will be required to refurbish at least 3% of their

buildings (by floor area) each year, which is about twice the currently prevailing rate for the European building stock".

The significant challenge of retrofitting public buildings must be accompanied by the measures that will secure that the process of reducing energy use will not bring any harm to building occupants by reducing indoor environmental quality and increasing the risk of discomfort and health problems. The retrofits should additionally not result in the economic losses in case the work efficiency will be reduced or the learning process will be slowed down.

Educational buildings create a very special challenge when energy retrofits are taken into account. These buildings are occupied by particularly vulnerable populations. Furthermore, there is usually a very short time that can be allocated to perform renovations without considerable disruptions to normal activities: Usually the appropriate periods are summer or winter holidays, i.e. 1-2 months in summer and 1-2 weeks in winter. Renovations of educational buildings must address these very specific requirements, while the methodology that is used to retrofit these buildings cannot be merely adopted by duplicating the methodology used to retrofit other public buildings. One potential solution to the challenge of retrofitting school buildings is the use of prefabricated elements that can be assembled in the factory or onsite, and can be installed in a very short time available for performing the renovation.

The project Renew School on "Sustainable school building renovation promoting timber prefabrication, indoor environment quality and active use of renewables" granted in the frame of Intelligent Energy Europe Programme attempts to disseminate one of the solutions allowing quick and robust energy retrofits of educational buildings. It focuses on retrofitting facades containing wooden elements, either prefabricated or not. The objective of the project is to promote the timber facades and additionally to promote solutions that will create decent conditions supporting learning and proper development of children. To meet the project objectives, a sample of educational buildings in Europe is selected. These buildings are new or have undergone renovation. The solutions used in these buildings are disseminated during the course of the project, including sharing of the lessons learnt during the renovation process. In addition, other instruments important for increasing the rate of renovations are discussed including contact with stakeholders or raising the financial support. The sample of buildings selected as examples of energy retrofits within the Renew School project are called frontrunners. They had to fulfil specific criteria to be selected including reduced energy use by at least 66% (in form of the primary energy) compared with conventional buildings, at least 20% of energy used from renewable energy sources, and use of timber facades.

The particular objective of the present paper is promoting of the technological solutions for achieving high quality of indoor environment in educational buildings. There is a general agreement among different stakeholders that indoor environmental quality (especially thermal environment and air quality) is very important in educational buildings. This has been documented in many research studies. Poor classroom environmental conditions have an impact on the learning ability of pupils, their well-being, health and attendance. Poor indoor air quality in classrooms is a particular

concern for children in elementary schools, who have generally greater sensitivity to atmospheric pollution than adults do. Furthermore, their bodies are still growing and any negative health effects may detriment the proper development. These children are more active, so they generally breathe higher volumes of air relative to their body weights. They also have lower capacity to deal with toxic chemicals. This is making them even more vulnerable to harmful pollutants. Particular problems arise if they additionally have allergies, asthma or hypersensitivity, respiratory problems or cardiopulmonary pathologies. Because children have narrower airways than adults do, the irritation caused by air pollution can much quicker result in the obstruction of airways. Poor classroom environmental quality can also have negative effects on teachers although the scientific data on this issue is quite limited. If the analogy is made to the research data from offices, it is likely that poor indoor environmental quality in educational buildings will affect cognitive abilities, result in health symptoms, general poor well-being and also higher sick leave. This will certainly affect the teaching process. Unlike children, who have very few possibilities of reporting the complaints, adults can much more efficiently influence decisions resulting in better indoor environmental quality and if necessary, when no other options are available, can change the workplace.

This paper presents the measurements of indoor environmental quality in the subset of frontrunner buildings selected by the Renew School project. The measurements are compared with the conditions in the selected conventional educational buildings that did not undergo the renovation process. The main objective was to examine whether renovations with timber facades resulting in significant energy reductions had measurable impact on indoor environmental quality in these buildings. Another objective was to examine whether the measured conditions in frontrunners do correlate with the technical systems and solutions installed in these buildings for the purpose of achieving high indoor environmental quality. Physical measurements were carried out as well as subjective evaluations of conditions in these buildings were performed by both pupils and the teachers.

2. Methods

In the framework of Renew School project, 19 frontrunner buildings were selected. These were either school buildings or kindergartens that used timber facades. Although the original intention was to select only renovated buildings, due to difficulties to find appropriate buildings also new buildings were included. Frontrunner buildings were located in different regions of Europe, with different climates, stretching from the north of Europe (Denmark) to the southern parts (Italy). Details of the frontrunner buildings can be found on the Renew School webpage (<http://www.renew-school.eu/en/home/>).

Ten buildings were randomly selected among the frontrunner buildings for the detailed measurements of indoor environment. The details of these buildings can be found in Table 1. In addition, five buildings were selected by random in different countries, which did not undergo the renovation. These buildings are called conventional buildings and were selected to create some reference for the frontrunner buildings.

In each building at least one space (classroom or common playroom) was selected. The measurements were performed in this space. In case of the school buildings it was the class used by children from the 3rd, the 4th or the 5th grade. In case of kindergartens it was the common area that was mainly used by the children and the teachers.

Continuous measurements of temperature, relative humidity, carbon dioxide concentration (CO₂) and in some cases light intensity were carried out in the selected spaces for the period of 2 months in the heating season of 2015 (between January and April). The calibrated measuring station containing the logger and the CO₂ monitor was placed centrally in the space to support the measurements. The station was deployed by the project partners or the janitors after receiving detailed instructions on how and where the station should be located.

In addition to physical measurements, the subjective evaluations of the conditions in buildings were completed by presenting questionnaire to teachers and children; the questionnaire contained questions pertaining to perceptions of the environment, well-being and health symptoms experienced in the building. An example of the questionnaire is shown in Figure 1. The answer to each question was given by marking the smileys. The questionnaire was presented to children in the space where the physical measurements were made. They answered the questions included in the questionnaire once during the period when the physical measurements were made. Likewise the teachers were presented the questionnaire only once during the period of physical measurements. However in this case the questionnaire was distributed to all teachers working in the building to increase the sample size. The questionnaires were presented by the project partners or janitors after receiving detailed instructions. The scales were translated into the local language by the partners of the Renew School project. No back translation was made to verify whether the translation was accurate.

The measuring data and the subjective ratings made by the pupils and the teachers were analysed by the Authors of this paper. Only descriptive statistics was made and no inferential statistical analysis of the obtained results was performed.

In case of the physical measurements, the measurements performed from Monday to Friday between 9 am and 2 pm were used. The data from the periods when the children were not present in the classrooms or playrooms were removed; the criterion for removal was the CO₂ concentration below 550 ppm. Time-weighted averages were calculated and block charts created representing distribution of typical conditions in these buildings during the measuring period.

In case of subjective evaluations provided on the printed questionnaires, the ratings of children and teachers were digitized and the digitized data checked for gross errors. Then the block charts were created separately from the assessments of children and the teachers and separately for each building. Radar charts were made to summarize the reported health symptoms and complaints.

3. Results

Figure 2 shows the measurements of temperatures and CO₂ concentrations in the frontrunners and in the conventional buildings.

Except for the few unusual events, the temperatures were between 22°C and 25°C, perhaps slightly higher in some frontrunners but since the population of frontrunners and conventional school buildings was quite different in size it is difficult to generalize these observations. In two kindergartens the temperatures were quite low, around 20°C on average and in one conventional school it was above 25°C. Again there are too few data to generalize these observations. The temperatures fluctuated within ± 0.5 -1°C around the mean, slightly less in the frontrunner buildings, as expected. In some frontrunners the temperature was closer to 22°C. The reason could be the use of solutions resulting in reduced solar heat gains (Table 1).

The measured concentrations of CO₂ were below 2,000 ppm, which is an action level in many countries. In one frontrunner the CO₂ was higher than 2,000 ppm but this was probably quite unusual, as the ventilation system in this kindergarten was idled. The measurements of CO₂ suggest that ventilation efficiency in the frontrunner buildings was higher because CO₂ levels were generally lower than in the conventional buildings. The difference could also be due to the difference in population of children in different spaces where the measurements were made but this explanation is quite unlikely considering that the difference is quite systematic. The difference in average CO₂ concentration of 200-300 ppm between conventional buildings and frontrunners suggests that the difference in ventilation rates per person reached about 3-4 L/s between these two types of buildings.

Figure 3 shows the subjective evaluations of thermal environment and air quality in the frontrunners and conventional buildings. The ratings made by the teachers and pupils are shown separately.

Generally, the ratings of thermal environment indicate that both teachers and children felt warm - most of the ratings were in the upper part of the scale. There were large variations in ratings as is expected in case of the subjective evaluations. There was no systematic difference between evaluations made by the teachers and the pupils. The estimated average Predicted Mean Vote (assuming activity level of 1.2 met and clothing insulation of 1 clo) was also generally between neutral and slightly warm level. The estimated Predicted Percentage of Dissatisfied was generally below 15%.

The ratings of air quality showed that the air in frontrunners and conventional buildings was on average rated to be neither fresh nor stuffy. There were large differences in air quality rated by the teachers and pupils in frontrunners, some being rated to have fresh air and some to have quite stuffy air. Such large differences are not seen in Figure 2, which shows small difference in average measurements of CO₂ between frontrunner buildings. This may suggest that CO₂ is not a very well predictor of the actual perceived quality of air for this population of buildings. This result can also suggest that there could be strong sources of pollution in the buildings where the air was judged to be stuffier. This also suggests that when designing ventilation in schools, it is not sufficient to consider only the ventilation rate dealing with the dominant source of pollution. Other sources should be considered as well and at best avoided. Figure 3 shows also some tendency in the sensory ratings of air quality namely that teachers rated the air to be stuffier than pupils did.

There were no large differences between frontrunners and conventional buildings as regards the measurements of relative humidity and light level as well as regards as other subjective evaluations both related to environmental factors such as noise and light or well-being and health symptoms (data not shown).

4. Discussion

The purpose of the present work was to examine whether energy retrofits in schools have an impact on indoor environmental quality (positive, negative or benign), and additionally whether there are any specific solutions that are used in retrofitted buildings that particularly benefit indoor environmental quality in these buildings. The answer to both questions is negative.

Present measurements cannot clearly document that the retrofits have either negative or positive effect on indoor environment in educational buildings compared with the conventional buildings that have not undergone renovation. There is perhaps small indication that ventilation effectiveness is higher in retrofitted buildings but this can also be a spurious effect caused by the difference in number of pupils present in the classrooms during the measurements. There is also some evidence that temperature is better controlled in these buildings (and less fluctuating as well). Taking into account that there is very limited information on the performance of buildings that are subjected to energy retrofits, the measurements presented in this paper create a significant contribution in the discussion on the effects of energy retrofits. They show that within the scope of measurements performed, the energy retrofits do not create the risks for reduced indoor environmental quality. Remarkably, at the same time it should not be expected that these retrofits will bring measurable and significant benefits as well. The latter is probably because the systems supporting indoor environment in retrofitted buildings are much alike (Table 1). They include traditional heating systems, perhaps sometimes with floor heating, and typical mechanical ventilation systems, either with central or local air handling unit. This is yet another reason why it was difficult to find any relationship between the systems installed in the frontrunners and the indoor conditions. These buildings simply performed very similar.

One important observation resulting from the present exercise is that there have been some differences in the ratings of air quality in the frontrunners. This may suggest that in order to achieve remarkable improvement of indoor air quality, the energy retrofits should be supplemented with identification of potential sources of pollution related to building materials and furnishing, which need to be replaced by the low-polluting alternatives.

Present measurements, albeit quite informative, have several limitations and need to be interpreted and discussed taking these limitations into account. Non-random group of frontrunners was selected. Some of the frontrunners were new buildings so they do not qualify as retrofits. It is difficult to judge whether the selected frontrunners create a true representative sample of buildings that have undergone the energy retrofit. The measurements were made only in the subset of buildings, in one classroom and in one season. It would be useful to make measurements in the non-heating season and at least in few more spaces within each frontrunner to have a better understanding of the actual

conditions in classrooms and playrooms. Such measurements were performed in one frontrunner and there were quite notable differences in measurements between classrooms. In addition, the number of conventional buildings was too low to create the proper reference for the measurements in frontrunners. Finally, it is difficult to make general conclusions based on the subjective evaluations. Often only few teachers responded (generally <10) and in case of children no more than 20-25 responses were obtained.

Despite the above limitations, the present approach (with small improvements such as inclusion of measurements in at least three spaces in each building) can be used to make a crude characterization of school buildings that have undergone energy retrofit. The present results do show that it is not sufficient to make only physical measurements and that they need to be supplemented with subjective evaluations including simple ratings of thermal sensation and air quality. These evaluations should be made by both pupils/children and teachers to ensure representative votes.

5. Conclusions

- Measurements were performed in the new and retrofitted educational buildings and compared with similar measurements in conventional buildings.
- No indications were observed that new and retrofitted buildings reduce indoor environmental quality. Likewise they do not significantly improve these conditions as well.
- There were no specific systems installed in new and retrofitted buildings that would create significant benefits for the indoor environmental quality.
- Physical measurements are not sufficient to characterize conditions in educational buildings. They need to be supplemented by simple subjective evaluations of both teachers and children.

Acknowledgments

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IS YOUR CLASSROOM USUALLY (please put a cross on the right smiley):















Too cold								Too warm
	G	E	D	A	D	E	G	
The air is fresh								The air is bad
	A	B	C	D	E	F	G	

Fig. 1 Ecerpt from the quationnaire presented to children and teachers

Table 1. Description of frontrunner schools where the measurements were performed

Frontrunner	Type N(new)/R (renovated)	Energy use (kWh/m²)	Ventilation	Other solutions	Other solutions
B-S1	School (R)	13 (heating), 148 total	Central balanced mechanical ventilation, co ₂ controlled	heat recovery 84%	free cooling ground heat exchanger
B-S2	Kindergarten (N)	13.3 (heating) + 2 (cooling)	central balanced mechanical ventilation system	heat recovery 83%	
A-S1	Secondary school (R)	15 (heating) ; 44 final	decentralized mechanical ventilation system with heat recovery (80-90%); 100-500 m ³ /h		integrated ducts in the new facade (ventilation grills)
A-S2	Secondary school (R)	12 (heating); 56 kWh/m ²	Central balanced mechanical ventilation, co ₂ controlled	heat recovery 90%	night cooling
A-S3	Primary school and kindergarten (R)	8 (heating); 35 (total)	Central ventilation system, co ₂ controlled	heat and moisture 80%	
SI-K1	Kindergarten (N)	22 (heating)			floor and wall heating (the latter for cooling); blinds outside
PI-K1	Kindergarten (N)	35-40	Central balanced mechanical	heat recovery up to 95%	floor heating
DK-S1	School (N)	41	Hybrid (common areas, sports hall); MV winter, stack summer	Preheating of intake air in ground ducts	
It - K1	Kindergarten (N)	24	Central mechanical (2,000 m ³ /h)	heat recovery >90%	adiabatic humidification (winter)

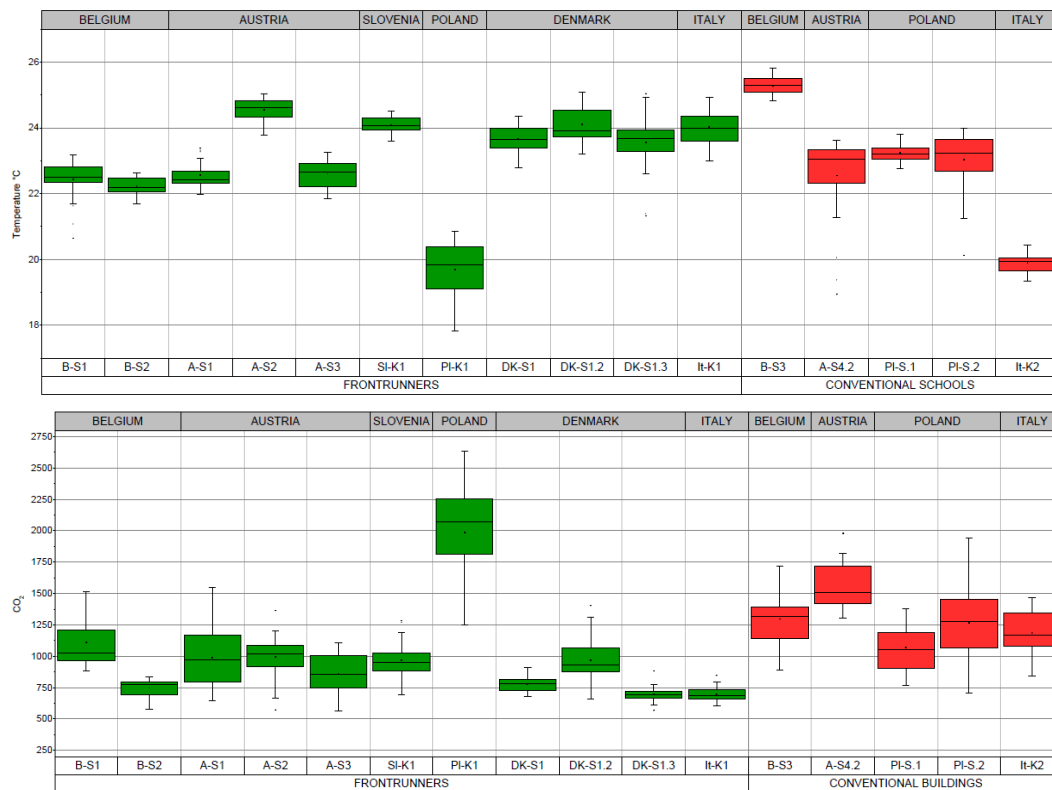


Fig. 2 Results of temperature and CO₂ measurements



Fig. 3 Results of subjective evaluations of thermal sensations and air quality